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A Fuzzy System for the Assessment of Landslide Monitoring Data

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A Fuzzy System for the Assessment of Landslide Monitoring Data

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Abstract

In many cases landslide areas can be divided into several blocks, which are moving with different velocities in different directions. So, in case we are able to detect block boundaries, landslide monitoring can be performed more efficiently. The information about the relative movement of these blocks is a very important indicator for future movement behavior, if monitored very precisely at the block boundaries with continuously measuring geotechnical sensors.

To detect the boundaries of the blocks the following algorithm is used: the displacement vectors of the observed points (out of a geodetic deformation analysis) will be analysed by an affine coordinate transformation. The assignment of the observed points to the different blocks is done by an iterative algorithm; the thresholds for the several steps of the algorithm are calculated by a fuzzy system. The input parameters for this fuzzy system are e.g. the residuals of the transformations and strain parameters calculated from these transformation steps.

Finally, an example for application of this fuzzy system will be given.

Zusammenfassung

Meist können Hangrutschungsgebiete in einzelne Bereiche mit verschiedenen Bewegungsrichtungen und -geschwindigkeiten eingeteilt werden. Wenn mit Hilfe geodätischer Überwachungsmessungen diese einzelnen Teilblöcke des Rutschhanges ermittelt werden, kann über diese Blockgrenzen hinweg mit lokal messenden geotechnischen Sensoren permanent und hochgenau die Relativbewegung der Blöcke zueinander registriert werden. Daraus können wichtige Informationen über das zukünftige Bewegungsverhalten des gesamten Bereiches gewonnen werden.

Ein Teilbereich dieser Aufgabenstellung ist die Detektion der Grenzen zwischen den einzelnen Blöcken des Rutschhanges. Die Idee ist, dass geodätisch überwachte Punkte, die gemeinsam auf einem dieser Teilbereiche liegen, ähnliche Bewegungen ausführen. Mittels einer überbestimmten Affintransformation werden aus den Verschiebungsvektoren sowohl Starrkörperbewegungen (Translation und Rotation) als auch die Verzerrungen der verschiedenen möglichen Teilbereiche ermittelt. Anhand von Kenngrößen der Transformationen (z.B. Residuen, Strainparameter) können in einem Fuzzy System die einzelnen Teilblöcke des Rutschhanges bestimmt werden.

Anhand eines Beispiels werden die Komponenten des Fuzzy Systems vorgestellt.

1. Introduction

Landslides are one of the major types of natural hazards worldwide. Every year thousands of people are injured or even killed. Additionally, many buildings and infrastructure like railroads and traffic networks are destroyed. E.g., only in the US, 25 to 50 people are killed per year and the economic damage reaches US$ 2 billion. So, there is an urgent need for a suitable monitoring and alarming system. The project OASYS (Integrated Optimisation of Landslide Alert Systems) was started to fulfil these requirements by a multi-disciplinary approach [1].

OASYS consists of several steps:

1. At a regional scale, potential landslide areas have to be identified. This is done by satellite images (remote sensing data, INSAR), topographic and geological maps, historical reports,...
2. At a local scale, for each of these landslide areas a monitoring system is installed. First, a geodetic network is observed in several epochs and based on these measurements the block boundaries can be identified.
3. In a next step, high precision geotechnical sensors are installed across the block boundaries to permanently observe the relative movement of the blocks.
4. A knowledge-based system is used to analyse the collected data and to support the decision making authorities in case of danger.

This paper deals with one part of the project OASYS, the detection of the block boundaries based on geodetic deformation measurements.

2. Algorithm for block detection

We assume that the geodetic networks have been measured periodically and the coordinates and displacement vectors were calculated out of a geodetic deformation analysis. The assumption for our method is that displacement vectors for all observed points are available. The block detection algorithm is the necessary step to proceed from the measurements of the geodetic network to the following installation of the high precision geotechnical sensors in the area under investigation.

The block detection algorithm (see fig. 1) starts with the identification of a minimal block of four points (explanation see section 2.1); in the following iterative procedure other neighbouring points are added to the block until it is 'complete'. This assessment of completeness is done by a fuzzy system. Then the algorithm starts again, identifying another minimal block out of the remaining observation points. The practical implementation of the algorithm is described in section 4.

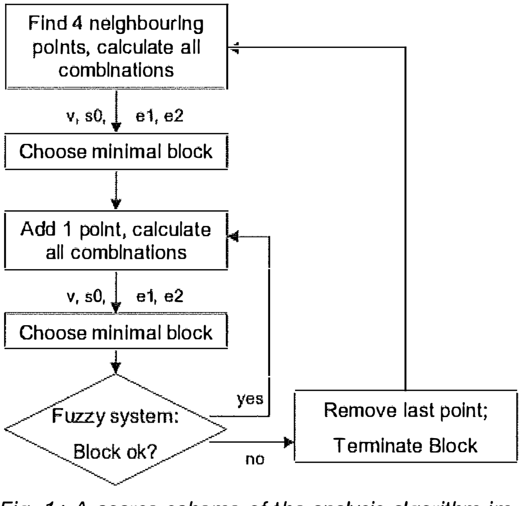

Fig. 1.: A coarse scheme of the analysis algorithm implemented in MATLAB.

2.1. Affine coordinate transformation

The block detection algorithm is based on the displacement vectors of the observed points. The idea is to use an over-determined affine coordinate transformation to assess the movement of the points between two subsequent epochs of measurements. This means that the coordinates of the points of epoch n are mapped onto the coordinates of the same points of epoch n+1. If some points move in the same direction (assuming that they are lying on one common block) then an over-determined affine transformation will give small residuals and a small standard deviation. In case points of different blocks were considered simultaneously the standard deviation will be significantly larger.

In two dimensions, the approach reads as follows:

$$\begin{aligned} y_{n+1} &= a \cdot y_n + b \cdot x_n + c \\ x_{n+1} &= d \cdot y_n + e \cdot x_n + f \end{aligned} \tag{1}$$

where y_n, x_n...coordinates of epoch n
y_{n+1}, x_{n+1}...coordinates of epoch n+1
a,..,f...transformation parameters

To solve this equation system, three identical points are necessary; for an over-determined solution at least 4 points have to be used. So the algorithm starts with a minimum block size of 4 points.

The six transformation parameters (a,..,f) can be interpreted as two translations (t_y, t_x), two rotations (w_y, w_x) and two scale parameters (m_y, m_x):

$$\begin{aligned} a &= m_y \cdot \cos w_y \quad & b &= m_x \cdot \sin w_x \quad & c &= t_y \\ d &= -m_{y \cdot \sin w_y} \quad & e &= m_{x \cdot \cos w_x} \quad & f &= t_x \end{aligned} \tag{2}$$

The six-parameter approach was chosen because of the special properties of landslides: The movement of a block can be described by a translational part and a rotation/distortion [2]. In most cases the distortion in the direction of the movement is larger than in other directions. So a second scale parameter is necessary to fully describe the anisotropic strain conditions.

2.2. Strain analysis

Due to the small displacements, the six transformation parameters usually are not meaningful (i.e. a clear distinction of the several blocks is not possible out of these parameters). On the other hand the affine transformation is analogous to a strain analysis assuming homogeneous and infinitesimal strain (e.g. [3], [4]). So there is a direct relation between the transformation parameters and the infinitesimal strain components e_{xx}, e_{yy} (rate of change of length per unit length in direction of x-axis resp. y-axis), e_{xy} (= e_{yx}, rate of shear strain) and the derived rotation angle ω. The strain ellipse represented by the semi-axes e_1, e_2 and the orientation θ of the maximum strain rate is calculated from these strain components analogous to the geodetic point error ellipse.

In contrast to Welsch [3], who recommends not to use translation parameters, here an integration of the translation parameters (t_y, t_x) seems useful to fully describe the movement pattern of a block to avoid that the strain parameters are distorted due to translational movement.

2.3. Indicators for the block detection algorithm

The indicators used for the analysis in the fuzzy system can be determined by the results of the sequence of affine transformations. Some of the indicators are presented here:

- The standard deviation s0 is used for a first evaluation of the block properties. Investigations have shown that especially the change of the standard deviation from one step to the next one is a very important indicator for the assessment if the block is still 'correct'.
- The next parameters for the fuzzy system are the two semi-axes of the strain ellipse (TISSOT indicatrix): e_1, e_2. In case a point does not belong to the block investigated, e_1 and e_2 become significantly large. Here, the absolute values on the one hand and the change of the parameters between two subsequent steps of iteration on the other hand are used.
- Investigations have shown that the variation of the residuals is a good indicator to distinguish between a correct block (all points belong to one block) and an incorrect block (point of a neighbouring block is included). The interquartile range (used in the exploratory data analysis) gives an estimate of the variation of the residuals in every step of the transformation (see fig. 2). The interquartile range was analysed for 170 cases consisting of 4 points. The interquartile range of the 31 correct blocks (= 4:0) is significantly smaller than for the incorrect blocks (81, 58 cases resp.). '4:0' in fig. 2 denotes that all 4 points are lying on one block, '3:1': 3 points on one block, 1 point on the neighbouring block, '2:2': 2 points per block.

3. Fuzzy system

For the implementation of the algorithm MATLAB was used. It provides an initial fuzzy sys-

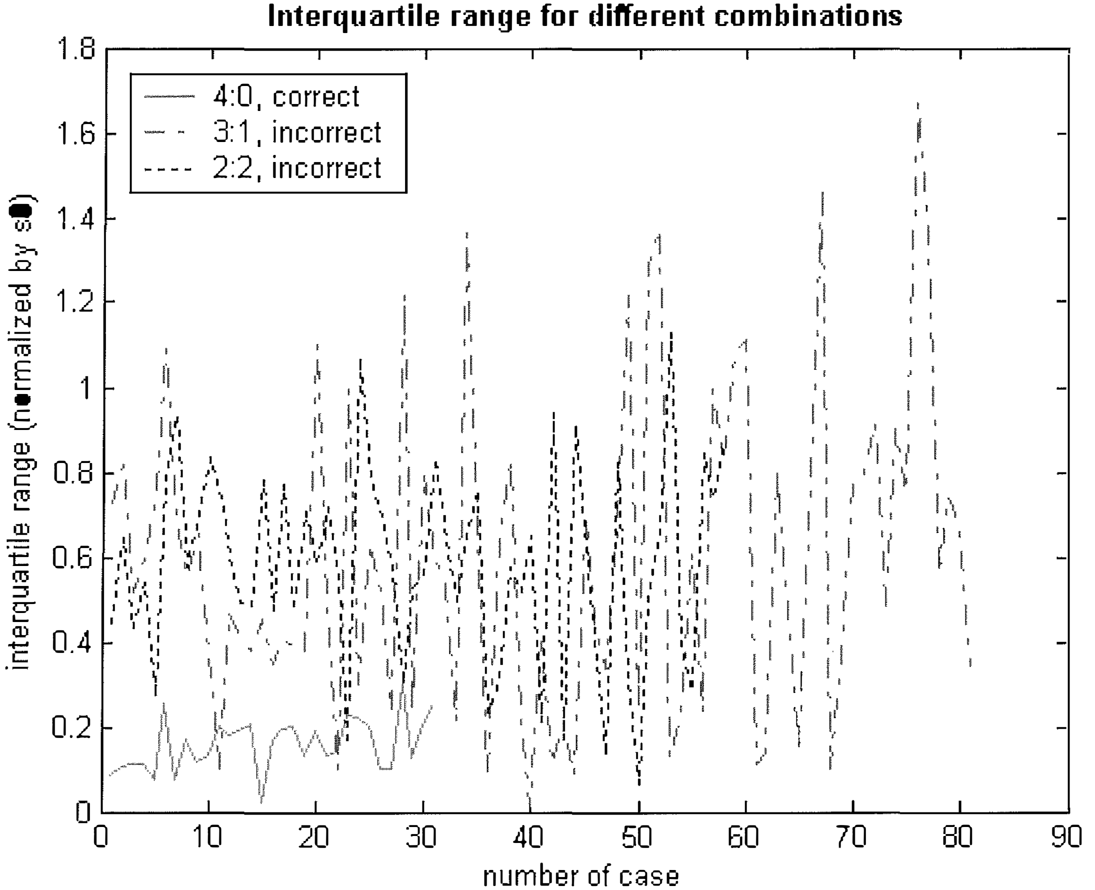

Fig. 2.: Interquartile range for 170 different cases.

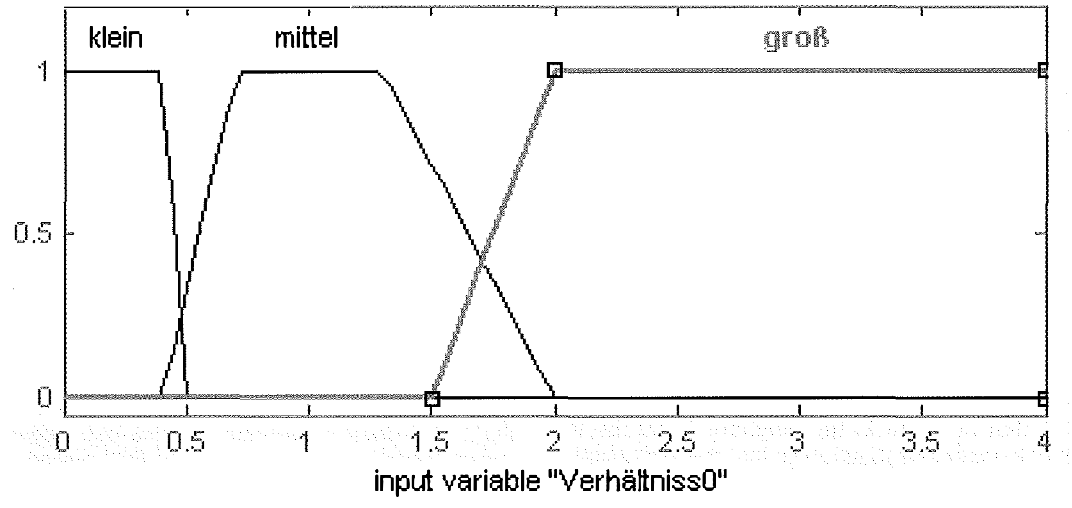

Fig. 3.: An example for the membership functions of an input parameter.

tem, which supports all necessary calculation methods (membership functions, methods for fuzzyfication, inference system, defuzzification). The developper of the fuzzy system has to choose the suitable methods, input and output parameters for his application.

3.1. Input variables and membership functions

The input parameters of the fuzzy system were already mentioned before, e.g. the change of the standard deviation of subsequent steps, strain ellipse parameters e_1 and e_2,... To use the input values in the fuzzy system, the 'sharp' values have to be fuzzified. Therefore, membership functions are used. MATLAB provides many membership functions, such as piecewise linear functions, the Gaussian distribution function,...

For most of the input parameters the membership function type 'trapezoidal' was chosen in a rather intuitive way. The inputs are split in 3 resp. 5 membership functions (per input). An example for the input parameter 'change of standard deviation s_0' is given in fig. 3. It is represented by three membership functions of type 'trapezoidal': small, medium and big.

3.2. Rules

The rules used in the inference system have been found empirically. At the moment, 25 simple rules have been implemented. But this topic is still under investigation.

The rules implemented must have a structure like: If (input is X) then (output is Y), followed by

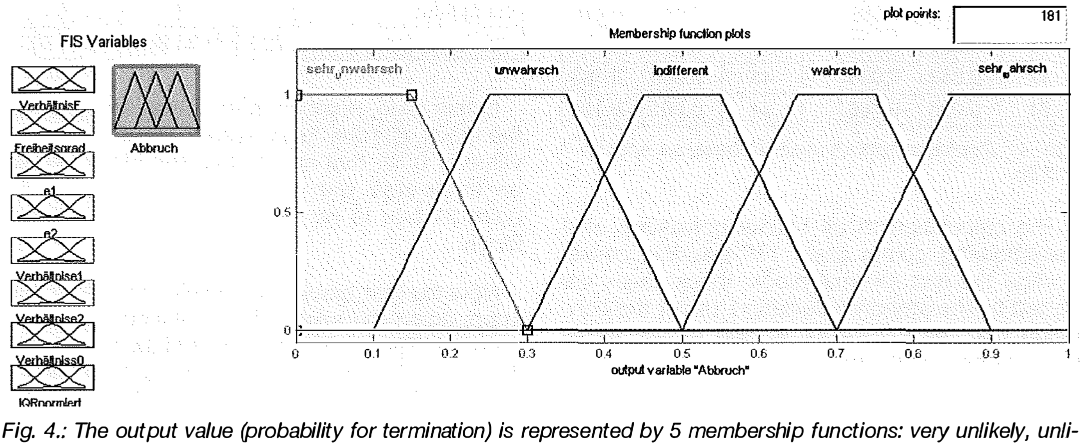

Fig. 4.: The output value (probability for termination) is represented by 5 membership functions: very unlikely, unlikely, indifferent, likely, very likely.

a weight for this rule, e.g. (1). Examples for some rules used in the inference system are:

If (e_1 is klein) then (Abbruch is unwahrscheinlich) (0.5)
If (e_1 is mittel) then (Abbruch is indifferent) (0.5)
If (e_1 is groß) then (Abbruch is wahrscheinlich) (0.5)

3.3. Output

After the evaluation of the actual values of the input parameters, a fuzzy set for each output variable exists that needs defuzzification to get a single, 'sharp' output value.

Here only one output is implemented. It represents the probability that the block is complete, i.e. that no point in the neighbourhood fits the block under investigation so that the search algorithm has to be stopped. The output value is represented by 5 membership functions, see fig. 4.

4. Example

In this section the algorithm is tested with the so-called Delft network. This simulation of a deformation network consists of several epochs with different movement patterns. The simulated measurements (distances and directions) can be found in [5]. In this testing scenario, epochs 1 and 3b were used to calculate a geodetic deformation analysis using the software PANDA [6]. The displacement vectors, which are the results of the deformation analysis, are the input for the block detection algorithm (see fig. 5 and tab. 1).

Point	dy [m]	dx [m]
3	0.232	0.158
5	0.197	0.180
11	−0.021	0.339
13	−0.072	−0.069
15	−0.087	0.032
17	−0.058	0.033
21	0.025	−0.166

Point	dy [m]	dx [m]
35	−0.054	−0.121
37	−0.035	0.004
39	0.113	0.248
41	0.042	0.270
43	−0.018	−0.181
45	0.002	−0.186
47	0.001	−0.124

Tab. 1.: Displacements dy and dx between epochs 1 and 3b.

The calculation of all blocks consisting of 4 neighbouring points gives 170 possible cases. To find the first minimal block, these cases are sorted by the standard deviation, under the condition that the values for e_1 and e_2 are within user-chosen limits (necessary to consider the actual material properties).

So the first block determined by the algorithm consists of the points 3, 5, 11, 41 with the stan-

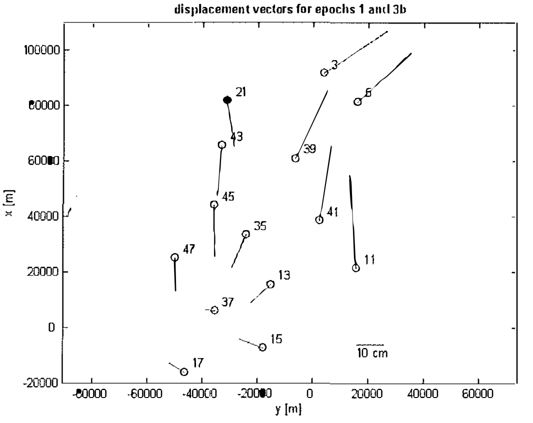

Fig. 5.: Graphical representation of the displacement vectors for the epochs 1 and 3b of the Delft network.

dard deviation s_0 = 9.9 mm. In the next step all the neighbouring points are used to find the next point of the block:

Possible candidates	13	15	21	35	**39**	43
std dev s_0 [mm]	78.3	59.5	52.6	66.2	**12.7**	55.8

The algorithm decides that the best candidate for a fifth point at the block would be point 39 because of the minimal standard deviation s_0 = 12.7 mm. The fuzzy system now calculates all the necessary input parameters and after evaluation of the implemented rules it concludes with the following output (fig. 6).

The defuzzified output value is 0.30, that means a probability of 30 % that the block should be terminated. So the next step of iteration is started to find the sixth point of the block:

Possible candidates	13	15	**21**	35	43	45
std dev s_0 [mm]	94.4	72.3	**71.3**	86.9	76.4	76.7

In this case, point 21 is the best candidate for the block. But the fuzzy system gives an output value of 0.72, that means that the block should be terminated with a probability of 72 %. So point 21 has to be removed from the selected block.

Now the first block is complete. The algorithm starts again the search for a minimum block of 4 points. The combination of points 13, 15, 17, 35 with a standard deviation s_0 = 12.0 mm is chosen. The results of the next steps can be found in tab. 2. After 6 iterations the algorithm stops because all points have been used.

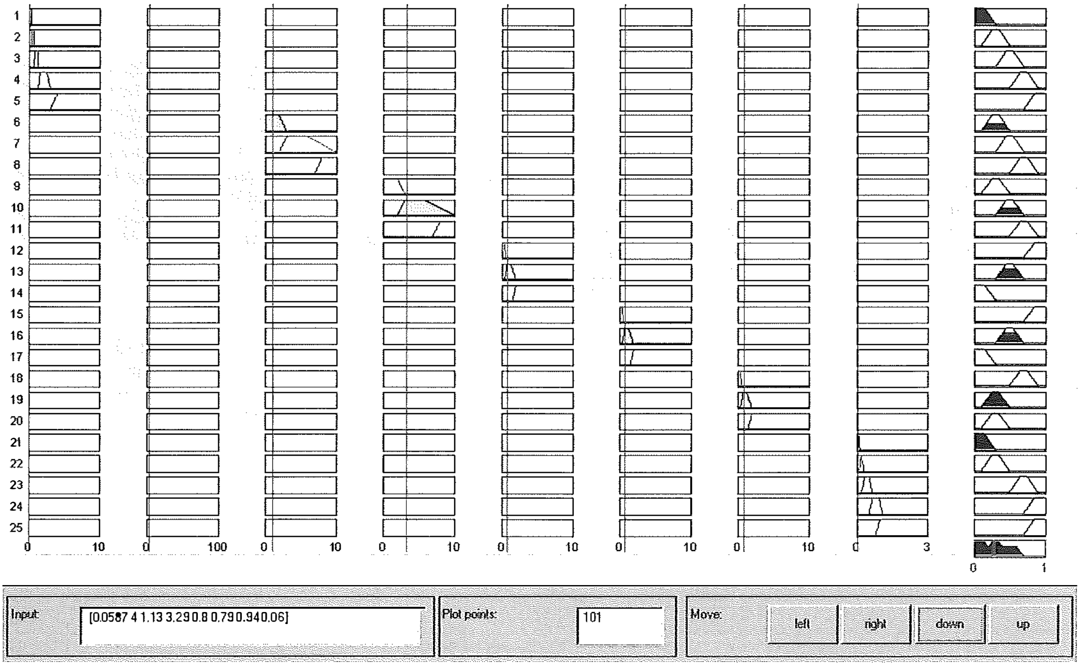

Fig. 6.: Screen-shot of the aggregation and defuzzyification process for the first run of the fuzzy system; output value: 0.30.

As a result, two blocks have been identified. This result corresponds to the pattern that people would intuitively find after viewing the graph of the displacement vectors (fig. 5 above).

The different block detection algorithms presented in [5] produce the same blocks as well.

5. Conclusion

In the past years, fuzzy methods were used more and more in geodesy (e.g. [7]). Fuzzy systems are a good method for the assessment of imprecise data or for the processing of linguistic variables because it is possible to reproduce the human way of decision making.

For the movement of a sliding area, it is hardly possible to build a suitable mathematical model fully describing all of the complex processes in the background (geology, hydrology,...). So this situation is well suited to be treated by fuzzy methods, where the knowledge of different sciences can be combined in a non-formal way. Here a possible assessment algorithm for landslide monitoring data is developed. The example of the Delft network shows that the problem given can be solved using a fuzzy system. But there is much more work to do; it is planned to include other input parameters like e.g. geological information (type of material of the area investigated). So the number of input parameters and rules will increase. Additionally, the fuzzy system will be tested on further examples.

Iteration number	Points included in the actual block									s_0 [mm]	Probability of termination
1	13	15	17	35						12.0	
2	13	15	17	35	47					11.9	0.30
3	13	15	17	35	47	45				11.0	0.30
4	13	15	17	35	47	45	37			17.1	0.39
5	13	15	17	35	47	45	37	43		24.3	0.48
6	13	15	17	35	47	45	37	43	21	31.6	0.50

Tab. 2.: Results of the subsequent steps of the algorithm. Point 21 is the last point, so the algorithm is terminated (neglecting the output value of the fuzzy system).

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References

[1] *H. Kahmen, W. Niemeier:* OASYS: Integrated Optimisation of Landslide Alert Systems. This issue of VGI.
[2] *A. Antonopoulos, W. Niemeier:* Formulierung und Test impliziter linearer Hypothesen bei der geodätischen Deformationsanalyse. In: W. Welsch (Hrsg.): Deformationsanalysen '83. Beiträge zum Geodätischen Seminar 22. April 1983. Schriftenreihe Wissenschaftlicher Studiengang Vermessungswesen Hochschule der Bundeswehr München, Heft 9. München, 1983.
[3] *W. Welsch:* Description of homogeneous horizontal strains and some remarks to their analysis. In: Proceedings of the International Symposium on Geodetic Networks and Computations. DGK Reihe B, Heft Nr. 258/V. München, 1982.
[4] *F. K. Brunner:* On the analysis of geodetic networks for the determination of the incremental strain tensor. Survey Review Vol 25 , No. 192 (1979).
[5] *W. Welsch (Hrsg.):* Deformationsanalysen '83. Beiträge zum Geodätischen Seminar 22. April 1983. Schriftenreihe Wissenschaftlicher Studiengang Vermessungswesen Hochschule der Bundeswehr München, Heft 9. München, 1983.
[6] Handbuch zum Programm Panda (Programm zur Ausgleichung von geodätischen Netzen und zur Deformationsanalyse). GeoTec GmbH, Laatzen, 2002.
[7] *A. Wieser:* Robust and fuzzy techniques for parameter estimation and quality assessment in GPS. Dissertation, TU Graz. Shaker Verlag, Aachen, 2002.

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